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FINAL REPORT

Cost Growth— Effects of Contract Size, Duration, Inflation, and Technology

by

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and

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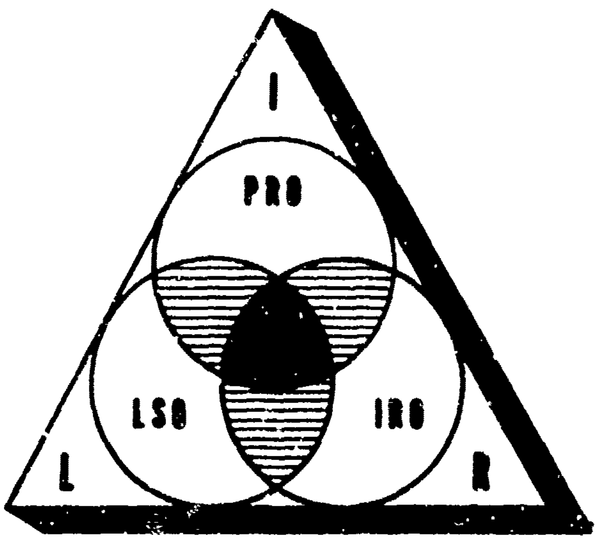

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COST GROWTH - EFFECTS OF CONTRACT SIZE, DURATION, INFLATION, AND TECHNOLOGY LEVEL

May 1972

by

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FOREWORD

The purpose of this report is to present selected findings resulting from research on contract cost growth and to indicate the future directions to be taken in studying cost growth. It is assumed that the reader is familiar with the March 1971 Army Procurement Research Office publication, "Production Cost Growth" and has a basic understanding of procurement and the subject of cost growth in general. This report contains results of further analyses of the data obtained in the DD Form 1500 and Contractor Performance Evaluation Forms.

ABSTRACT

This is a follow-on report to the Production Cost Growth Study dated March 1971. Results of the analysis of cost growth of major Army weapon procurements relative to the contract size, duration, technology level, and inflation are presented in some detail.

The results of this study indicate that the contract duration has a highly significant effect on cost growth while the contract size has a very mild effect. Inflation by itself was found to have a small effect on cost growth. It was found that the contracts which involve the highest level of technical sophistication experience significantly more cost growth than the others for Army contracts; but this was not found for the Navy or Air Force contracts.

This report also describes the data collected for the next segment of research on this cost growth project and previews the next scheduled report.

SUMMARY

1. Problem.

Contract cost increases in DOD have come under particularly close scrutiny within the last decade, resulting in criticism from many quarters. The implication of this criticism seems to be inefficiency at best, or basic dishonesty at worst. DOD is naturally sensitive to this type of criticism and has reacted strongly. Many studies and seminars have been sponsored for the analysis of the procurement process. Partly as a result of this, changes in the unwieldy procurement machinery have been implemented which add a tremendous amount of complication to the existing process. Cost growth in programs, systems and the individual component contracts still remain. It seems that the basic underlying causes of cost growth are not completely known. If these causes are in fact known, then we in DOD are merely covering our tasks by sponsoring studies aimed at discovering causes. It seems more likely that most of the grass-root causes are known - such as inefficient cost estimating procedures, unpredictable technical problems and the like - but the relationship among the many causes is so complicated that the machinery cannot be controlled at present.

2. Background.

The Army Procurement Research Office has been assigned the study of cost growth in the procurement of major Army weapon systems. The

overall study is statistical in nature, using the data contained in the DD 1500 Forms for all contracts (excluding FFP) over $1,000,000, Contractor Performance Evaluation Reports, and selected contract file data. The results of the first phase of the study are contained in the "Production Cost Growth" Report of March 1971. That research revolved around parameters endogenous to the procurement (contract type, commodity, etc.), and suggested several areas for continued study.

3. Objective.

The objective of this phase of the research is to determine whether the following factors contribute significantly to cost growth: contract duration (from time of definitization to time of close out), definitized contract dollar amount, inflation, and the level of technology involved in the work.

4. Data Base.

The data described in this report is found in the DD 1500 Forms for all contracts over $1,000,000 between 1959 and 1969, and in the data in AMC CPE files for the period 1966-1970. The Forms 1500 data were used for the analysis of cost growth with respect to contract initial cost, contract duration and inflation. There were 580 FPI, CPIF, and CPFF contracts in this data set. The CPE data is composed of 58 Army, 30 Navy, and 113 Air Force contracts, and contains a much finer breakdown of the contract cost information. Therefore this data set was necessary for that part of the study relating to the technology level.

5. Conclusions.

The findings indicate that the contract duration and initial cost both have an effect on cost growth, but were found not to be related to each other. Other factors such as inflation and number of modifications involved in the contract, are strongly related to duration so that all of these effects must be studied separately to assess the individual contribution of each to cost growth. In fact, inflation was found to have a very small but statistically significant effect. It was found that, for Army contracts, there are differences between different levels of technical difficulty with respect to cost growth characteristics, the highest level of technical sophistication yielding the greatest amount of cost growth. This was not found to be true for either the Air Force or the Navy contracts.

CHAPTER I

INTRODUCTION

The total amount of defense contract cost increases of actual money spent over and above the initial contract price, has amounted to many billions of dollars in the past two decades. Estimates of the average percent increase range as high as 400% for R&D contracts. In one particular case, an individual contract exhibited a cost increase of 11,667%.[1]

There are obviously many causes of this cost increase (not all undesirable), and these have been found to be basically of 5 types (listed here in order of desirability): (1) changes in quantity or technical requirements after definitization of contract; (2) inclusion of new techniques which are not known at time of definitization; (3) general price increases (inflation); (4) management inefficiencies such as the use of poor estimating procedures or lack of the required levels of technical ability; and (5) the buy-in (accompanied by subsequent increases).

Requirement changes, both in performance and quantity, cannot be considered undesirable, and changes in scope of work which are

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[1]*Note:* In this report the terms cost growth, overruns and underruns are as defined in Secretary Packard's Memo of August 5, 1970 for the Secretaries of the Military Departments.

designed to take advantage of recent advances in technology, may in fact, be highly desirable. It is noted that quantity changes are usually anticipated as is evidenced by the frequent use of contract options. Technology changes are not always more costly in themselves, but contractors normally obtain additional funds for implementing these changes.

The tax paying public is not usually made aware of the prevalence and importance of cost increases of this kind. From the sensationalism of the news media, the general public is led to believe that cost increases are a result of inefficiencies, inflation or graft. It must be admitted that the massive procurement machine is not immune to many of these charges. Unfortunately, among the categories of causes given above, the "buy-in" seems to be important.

The policy of "buying-in" on a contract refers to a contractor's deliberately underbidding all competition so that he will be assured of obtaining the contract. This usually means that his bid must be lower than his estimated costs of satisfying the work statement. One way to recoup the losses incurred in this situation is to obtain additional funds through contract modifications. For example, the contractor may propose a change designed to increase performance at a drastically inflated cost.

It would be very optimistic to feel that all cost growth resulting from inefficiencies, buy-ins and the like could be halted by pressure

from within the government. As a matter of fact, as an investigation proceeds beyond the descriptive or conjecture stage, the difficulty of identifying the causes by relating them to any concrete piece of datum, becomes apparent. Consequently, one is forced to develop abstract or indirect methods of investigation for such areas as the effects of inflation or the "buy-in". Some cost growth aspects are particularly exclusive. For example, how does one determine whether it is the government or the contractor who actually initiates a particular contract modification? While the change order may indicate that it is the government, other evidence may cast doubt on this.

In the first report (Production Cost Growth, March 1971), many inherent factors related to contract descriptive characteristics (e.g., contract type, commodity, type of work, etc.) were investigated. It was found that contract modifications account for 93% of cost growth, while overruns account for only 7%. Furthermore, cost growth, contract modifications and cost overruns all differ significantly for R&D and production contracts. A more detailed analysis showed: (1) a significant difference for total cost growth and modifications on production contracts between some contract types, and between commodity classes; and (2) a significant difference for cost overruns on production contracts between commodity classes, and between a sample of 10 individual contractors.

In this study the effects investigated are more external in nature. It seems likely that inflation would be a (minor) contributor to cost growth. Furthermore, cost growth might be expected to vary with the actual duration of the contract. These effects as well as the contract size (dollars) and the level of sophistication of the work involved will all be investigated. Part I of the cost growth study was concerned with those effects which are somewhat inherent to the contract itself. This report is more closely aligned with the study of effects which are more related to contractor behavior and the government reaction to it. In other words, this report is addressing issues more closely related to the entrepreneurial behavior of the contractor.

Previously, it was mentioned that contract modifications account for approximately 93% of cost growth as opposed to the 7% due to overruns. The most obvious question which this raises is: What types of contract modifications are the main contributors to cost growth and of these, which can be controlled?

The data which is presently available in the DD 1500 Forms does not contain a listing of modifications. This information is, however, contained in the CPE (Contractor Performance Evaluation) reports, initiated in 1966. These CPE forms were discontinued in FY 1971 and so only a very limited number of records are available. Furthermore, numerous inaccuracies have been noted in both the CPE and the 1500 forms. This imposes the requirement of locating a new data source.

Because of the requirement for new data, it was decided to schedule approximately 12 man weeks of travel devoted to the acquisition of information from actual completed contract files located in the various commands. This information breakdown is described in Figure 1 and includes a complete breakdown by modification type and amount for CPIF, CPFF, FPI and FFP type contracts. The FFP contract information was not previously available for the study, and represents new information. The data collection imposes the further requirement of about 60 man weeks of effort to transcribe the data to coding forms, coding sheets, IBM cards and finally to computer tapes.

In summary, the first report presented tests of relationships between contract characteristics and cost growth; this report presents the results of tests made on possible relationships between cost growth and selected economic and technical factors; and the next report will present results of tests of relationships between cost growth and various types of contract modifications.

COST GROWTH

1. Contract Number: ______________________

2. Contract Type: FFP____ FPI____ CPIF_____ CPFF____

3. Contractor: ______________________________________

____

4. Item: ______________________________________

5. Independent Government Estimate: ______________________

6. Competitive____ Negotiated____ Sole Source____

Cost Analysis____

7. Initial Contractor Proposal (DD-633):____________________

8. Initial Government Counter Offer:______________________

9. Date, Letter Contract: ____________________

10. Amount, Letter Contract: ________ ____________

11. Date, Definitization: ____________________

12. Amount, Definitization:_________________________

13. Incentive Arrangements:______________________________

14. Type Procurement:

Production____ R&D____ Services____ Other____

15. Negotiation Authority:_______________________________

16. Modifications (list on separate sheets).

FIGURE 1

CHAPTER II

DURATION AND SIZE OF CONTRACTS

As one begins to list possible significant contributors to cost growth, one of the first that comes to mind is the time duration of the contratt. This is reinforced by the fact that several other apparently contributing effects are related to it. For example, inflation obviously has a longer time span in which to take effect in longer contracts. Also, there is more time to introduce contract modifications, the major contributor to cost growth. As a matter of fact, duration would appear to be related to the total dollar amount of the contract which presumably is related to cost growth.

Before the data can be subjected to a regression analysis, it should be noted that while the contract size in our sample varies from $1,000,000 to about $55,000,000 and the contract duration ranges from 0 to 19 years, the percent cost growth varies from about -10 to 2,000. This would make the slope of the respective regression lines approximately .00003 and .0000004, and would almost certainly yield non-significant statistics. In order to overcome this difficulty, the contract sizes and durations are scaled downward by dividing by

the average contract size and duration for the entire sample, and the percent cost growth is divided by 100 yielding fractional cost growth. In this way, each scaled variable has a range of about 5 or 10. This procedure will transform the data in such a way that any relationship between cost growth and contract duration will be detected for prescribed confidence levels; however, if no significant relationship exists, then none will be introduced in this way.

The details of the preceeding paragraph can be expressed symbolically in the following way. Denote the initial, adjusted and final contract costs by C_i, C_a and C_f. Then the fractional cost growth, modifications and overruns are:

$$\frac{C_f - C_i}{C_i} \qquad \frac{C_f - C_a}{C_i} \qquad \text{and} \qquad \frac{C_a - C_i}{C_i}$$

respectively.

Let y_i represent the contract duration for contract number i. Then the sample average duration is $\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$ and the normalized contract duration for the contract is:

$$y_i' = y_i / \bar{y} \ .$$

The results of a regression analysis and the associated one way analysis of variance are given in Table II.1. The contract initial cost scaled with the average initial cost is included in the regression analysis. The scaling yields cost data with the approximate range 0 to 5.

Independent Variable: Cost Growth

Variable	Coefficient	Standard Error	F Values
Constant	-.265		
Initial Cost	-.176	.098	3.24*
Duration	2.237	.363	37.84***

Independent Variable: Overruns

Constant	-.056		
Initial Cost	-.010	.009	1.29
Duration	.172	.003	26.54***

Independent Variable: Modifications

Constant	-2.08		
Initial Cost	-.166	.097	2.89*
Duration	2.065	.363	32.38***

Independent Variable: Initial Cost

Constant	1.054		
Duration	-.054	.155	.122

$F_{.1,\ 1,577} = 2.72$ $F_{.05,\ 1,577} = 3.85$ $F_{.01,\ 1,577} = 6.66$

NOTE: In all of the tables in this text one, two or three asterisks denote statistics which are significant at the 10%, 5%, or 1% levels, respectively.

TABLE II.1

The multi-linear model is used in the regression analysis:

$Y_i = a_0 + a_1 x_{1,i} + a_2 x_{2,i} + \epsilon_i$, where

Y_i = fractional cost growth, or fractional cost overruns, or fractional contract modifications.

x_1 = normalized contract duration

x_2 = normalized contract initial cost

ϵ_i = the associated error (randomness)

a_0 = the constant term or overall average

This regression analysis was backed up by an analysis of variance, ANOVA, in which the contracts were divided into treatment groups by duration, a total of 14 groups. The results of the analysis of variance are given in Table II.2.

The analysis indicates that the contract duration is strongly related to cost growth, overruns and modifications. While the contract initial cost does have a statistically significant effect on modifications and cost growth, its effect is extremely mild. It must be remembered that the effect of inflation is related to duration, so that this effect must be investigated further for significance as one of the underlying causes. (See Chapter III) Furthermore, the total number of contract modifications could reasonably be expected to increase with the time duration of the contract. This will also be investigated at a later time in this study.

ANOVA: Cost Growth Vs. Duration			
	SS	DF	F
Between	2179.9	13	4.63***
Within	20486.8	566	
Total	22666.6	579	
Overruns Vs. Duration			
Be*ween	34.7	13	9.92***
Within	152.3	566	
Total	.87.0	579	
Modifications Vs. Duration			
Between	2031.7	13	4.35***
Within	20320.3	566	
Total	22352.0		

$F_{.01,\ 13,500} = 2.17$

NOTE: SS means sum of squares and DF means degrees of freedom.

TABLE II.2

It is very surprising that the contract size and duration are not related (Table II.1), since cost growth is related to both. Intuitively, it would seem that larger dollar amounts would be spent over longer time spans on the average, but, this does not seem to be the case.

The reason for this can be seen in the second column of Table II.1. The coefficients for initial contract cost versus percent cost growth, percent overruns, and percent modifications are all negative while the corresponding coefficients relative to the duration are positive. This means that the three effects listed above increase with contract duration (on the average) and decrease with contract initial cost. This helps account for the lack of dependence between duration and initial cost. A given change, say increase, in the average cost growth, would almost have to be a result of an increase in duration, but this could be accompanied by either a large increase or large decrease in initial cost.

While the results of the preceeding analysis should not be used for prediction, owing to the present indefiniteness in the model, some statements can be made from it. The regression equation from Table II.1 is:

$$Y_j = -.265 - .176 \cdot \frac{C_{ij}}{\bar{C}_i} + 2.237 \cdot \frac{D_j}{\bar{D}} ,$$

where y = fractional cost growth. The appropriate transformation then yields:

$$\% \text{ cost growth} = -.265 - .000037 \cdot C_t + 60.5 \cdot D.$$

This means that for each year increase in contract duration, there is a corresponding 60.5% <u>increase</u> in the rate of cost growth. Also, for each million dollar increase, there is a corresponding decrease of 37% in the rate of cost growth.

CHAPTER III

INFLATION

The investigation of the effects of inflation on cost growth requires special attention because of the lack of a direct indicator of inflation in the contract file data. Usually, inflation is taken into account in major procurement pricing procedures. Therefore, if the rate of inflation does not differ from that anticipated at the time of contract definitization, there will be no cost overrun or underrun as a direct result of inflation. It is reasonable, then, to search for a possible relationship between overruns and the difference between actual and anticipated inflation.

It is impossible to tell from the 1500 and CPE data, how much inflation was anticipated in a given procurement. Furthermore, it is unreasonable to assume that a relationship exists between the total dollar amount of contract modifications (for changes in scope, quantity increases, etc.) and inflation. This suggests attempting to obtain an indirect measurement of inflationary effects (with an apparent increase in the significance level of the subsequent statistical tests).

The main hypothesis in this section, is that overruns are positively correlated with increasing inflation. It also seems

reasonable to assume that estimates of "future" inflation, are based on past and present inflation indices. Finally, it is convenient to assume that if there are other contributors to cost overruns, (such as defective cost estimates) then all effects are additive with respect to inflation.

Obviously, in a quantitative analysis of an effect as complicated as inflation in the procurement process, it is necessary to develop a model which is easy to program (both in time and level of sophistication) and which on the average, yields accurate results. For the remainder of the mathematical analysis and the associated assumptions, the reader is referred to Appendix I.

The ANOVA based on the previous assumptions, and those in Appendix I, is given in Table III.1 below.

Overrun Vs. Inflation					
Source	d.f.	M.S.	F.	R.	t
Treatments	1	2.67	5.85	.17	2.42
Error	198	0.46			

Constant term = -.82 $\quad t_{.01} = 2.345$

Linear coefficient = .82 $\quad F_{.05} = 3.89$

TABLE III.1

The results · e encouraging. The estimated correlation coefficient R = .¹7 is somewhat low, but this is not surprising because of the gross assumptions involved. Furthermore, the associated t-value is highly significant indicating that the true correlation is not zero with 99% confidence.

There is another indication that the results are useful Notice that the sum of the constant term and the linear coefficient is zero, which should be the case if the model is an accurate description of inflation. In a period of no inflation, the inflation index, I, is equal to 1.0 (see Appendix I). Since inflation is the independent variable and the associated overrun is the dependent one, the model is $y = a_0 + a_1X$, where X = the inflation index and y = contract overrun. When X = 1 and $a_0 = -a_1$, then $y = 0$. This means that during periods of no inflation, the expected overrun is zero.

The inflation analysis was broken down further by type of contract for the following reason. Inherent in the analysis is the assumption that the contractor attempts to plan for inflation. The different types of contracts reflect, to a certain degree, different levels of risk involved in the contract costs due to uncertainties. It seems reasonable to suppose that as the risk increases, cost planning becomes more detailed. Because of the nature of the contract mechanism, the following order, FFP, FPI, CPIF, and CPFF reflects a decrease in

risk to the contractor from FFP to CPFF. Of course, FFP contracts do not have the overrun option. In any event, different overrun characteristi. , are expected between the different types. The results of the ANOVA's are given in Table III.2.

The analysis indicates that the FPI overruns are more highly correlated with inflation than are the other types. The R value is .26 which is significant at the 95% level. This is surprising because of the nature of the FPI contract overrun procedure. In this contract type, payments are not made above the ceiling price (which is usually about 120% of the target price). Regardless of the severity of the inflation experienced during a contract, the overruns are limited to approximately 20% of initial target costs. One would expect this to obscure the estimate of the correlation coefficient during periods of high inflation for FPI contracts.

The preceeding analysis is based on many simplifying assumptions and is admittedly coarse. The ne. result indicates a statistically significant small positive correlation between inflation and cost growth and no further analysis is indicated at this time. If it is found desirable to do so, a lot of specialized data will be required to further refine the analysis.

Overrun Vs. Inflation					
Source	d.f.	M.S.	F.	R.	t
		FPI			
Treatment	1	.148	2.88	.26	1.704
Error	40	.051			
Constant term = -4.16		$t_{.05}$ = 1.68			
Linear Coefficient = 4.13		$F_{.1}$ = 2.84			
		CPIF			
Treatment	1	.024	.170	.07	.403
Error	33	.139			
Constant term = -1.75		$t_{.1}$ = 1.31			
Linear Coefficient = 1.75		$F_{.1}$ = 2.87			
		CPFF			
Treatment	1	2.64	3.87	.17	1.898
Error	121	0.68			
Constant term = -10.8		$t_{.05}$ = 1.66			
Linear Coefficient = 10.8		$F_{.1}$ = 2.75			

TABLE III.2

CHAPTER IV

TECHNOLOGY LEVEL

It is highly probable that the degree of technical difficulty involved in the contract work would have an effect on cost growth. A high technical performance level implies greater uncertainty in the work, and hence a greater chance for unsuspected cost increases, while a low level of technology implies fewer unknowns and greater certainty in cost estimating.

The CPE reports include a measure of the level of technology involved in each contract. The contract officer assigns a grade from one of three levels. A rating of (1) implies the highest level of engineering sophistication (frequently involving new and untested scientific procedures), while grade (3) is used for the lowest level of sophistication.

A one-way ANOVA was conducted for the 58 Army, 30 Navy and 114 Air Force contracts separately and entire sample of 202. The results are given in Tables IV.1 and IV.2.

The computed F-ratio for Army contracts is highly significant and indicates a difference in the percent cost growth between different

ANOVA On Technology Level			
Source	d.f.	M.S.	F
ARMY CONTRACTS			
Treatments	2	153,798.--	12.2244
Error	55	12,581.21	
Total	57		
$F_{.05} = 3.15$			
NAVY CONTRACTS			
Treatments	2	3,491.0	1.08
Error	27	3,239.8	
Total	29		
$F_{.1} = 2.52$			
AIR FORCE CONTRACTS			
Treatments	2	36,193.2	1.72
Error	111	21,004.6	
Total	113		
$F_{.1} = 2.36$			
ALL CONTRACTS			
Treatments	2	16,603.445	.948
Error	199	17,510.73	
Total	201		
$F_{.05} = 3.04$			

NOTE: MS refers to the mean square.

TABLE IV.1

technology levels. The average percent cost growth for each category is given in Table IV.2. Notice that the average for the Army contracts for level (1) is about 7 times the average for the two lower levels. It is noted that there are only 6 contracts in this category, and the standard deviation is quite high which could indicate an outlier (one highly uncharacteristic observation). For this reason, the individual observations within this group are given in Table IV.3.

Notice that the ANOVA given in Table IV.2 indicates no difference in cost growth between technology levels for the entire sample and for the Navy and Air Force contracts separately. While this report is not intended to compare cost growth characteristics between services, this last result is somewhat surprising and suggests a comparison study in this area. Of course this difference might reflect merely a different reporting system between services, or something less drastic. Finding out the reason behind this seems a worthwhile endeavor.

Group Data for Technology Level			
Technology Level	1	2	3
ARMY CONTRACTS			
Sample Size	6	12	40
Mean	286.2	35.6	51.7
Standard Deviation	322.0	60.6	58.4
NAVY CONTRACTS			
Sample Size	10	5	15
Mean	25.8	31.6	58.0
Standard Deviation	37.1	30.7	71.4
AIR FORCE CONTRACTS			
Sample Size	34	27	53
Mean	54.6	114.7	55.9
Standard Deviation	72.4	233.8	119.1
ALL CONTRACTS			
Sample Size	50	44	108
Mean	76.6	83.7	54.7
Standard Deviation	143.6	188.8	93.9

TABLE IV.2

Army Contracts of Technology Level (1)

Contract No.	Cost $X10^{-6}$	% Cost Growth	Type Contract
1	10	48.6	Production
18	9.7	42.9	Adv. Dev.
26	.46	665.4	Production
33	26	60.5	O.S.D.
40	7	172.0	Adv. Dev.
60	4.8	727.0	Adv. Dev.

TABLE IV.3

CHAPTER V

CONCLUSIONS AND FUTURE WORK

The various effects which influence the cost growth associated with procurement contracts can be classified generally as endogenous or exogenous. Examples of endogenous effects are contract type, initial cost and level of technology. Inflation is an example of an exogenous effect. There are some effects which would be difficult to classify exactly; for example contract duration possesses elements of both types of effects. Phase I of this research project involved endogenous effects. Phase II (the work covered in this report) involves effects which are more exogenous in nature.

The recently completed research uncovered several interesting results, some of which are surprising and informative as well. Of the effects studied, the one with the most pronounced effect is the contract duration, that is the length of time from the definitization to the closeout. This is not unexpected, since there are so many other effects which are confounded with this one. For example, both inflation and total number of modifications increase with the contract duration. These last two effects require separate treatment,

therefore, to assess the importance of the effect of time. An analysis of total number of modifications and the number of modifications per year should be performed to see if this effect is significant.

Inflation was studied separately in this report. Since there are no direct indicators of inflation in the contract file data, an indirect method of analysis was adopted, and it was found that overruns and changes in rate of inflation are positively correlated, although the correlation is small. It was further found that different types of contracts exhibit different correlation coefficients with inflation.

The effect of contract size (initial negotiated cost) was studied and was found to have a statistically significant but very mild effect on cost growth. One surprising result is that contract duration and size are not related. That is, "larger" contracts do not necessarily require more time to complete.

Finally, the effect of the level of technical difficulty of the contract work was studied. It was found that the Army contracts which involve the highest degree of technical difficulty also suffer the most cost growth. This is not true for the Navy and Air Force contracts, however.

Phase III of the study has begun and the results will be ready for publication in about November 1971. The new data collected during the months of March and April 1971, should be available on

tapes for analysis by late July 1971. At that time, the analysis of the contract modifications will begin, and will comprise the major part of the remainder of the analytic effort. Furthermore, economic indicators for 100 of the largest corporations involved in procurement will be obtained for an analysis of cost growth relative to corporate economic strength. It is hoped that this analysis will yield information about the relative importance of the "buy-in" policy.

If there is enough time, the effect of inflation will be studied in more detail. Its effect has been detected, but the exact degree of the effect is still uncertain.

Several other parameters will be subjected to analysis. The authority to negotiate, the contractor's original position as reflected in the Independent Government Estimates and the contractor's original bid, the effect of sole source versus a competitive procurement, and the total number and annual frequency of the contract modifications will all be analyzed for effects on cost growth.

The new cost analysis data includes information from many FFP contracts. Since no previous analysis has been conducted on this type of contract, some of the Phase I and Phase II analyses will be repeated on this new data. It is felt that a comparison of cost growth characteristics between FFP and all other types of contracts will be most beneficial.

APPENDIX I

INFLATION INDICES

The inflation figures used in this study are obtained from the Federal Reserve Bulletin, January 1971, page A62, and are given in Table 1.

YEAR	WHOLESALE COMMODITY	SEQUENTIAL INFLATION RATIO
1951	96.7	-
1952	94.0	.972
1953	92.7	.987
1954	92.9	1.002
1955	93.2	1.003
1956	96.2	1.032
1957	99.0	1.029
1958	100.4	1.014
1959	100.6	1.002
1960	100.7	1.001
1961	100.3	.996
1962	100.6	1.003
1963	100.3	.997
1964	100.5	1.002
1965	102.5	1.020
1966	105.9	1.033
1967	106.1	1.002
1968	108.7	1.025
1969	113.0	1.040

The base period for the data of Table 1 is 1957-1959. Column three consists of the ratio of the inflated dollar value for the present year to the immediately preceding year. This figure represents the "inflation index" for each year and will be denoted by I_1, I_2, ..., I_{19} for 19 years (1951 through 1969).

To obtain an estimate of the conditional expected cost growth due to inflation given the inflation indices, let the expected total contract dollar amount which is affected by inflation be C, and let a_1, a_2, ..., a_n be the amounts expected to be spent during the n years of the contractural period. Finally, let m_1 and m_2 represent the number of months involved in the initial and final years of the contractual period, and let initial year be represented by j. Then the final contract cost, C_I is given by:

$$(1.1) \quad C_I = \left\{1+(I_j-1)\frac{m_1}{12}\right\} \left[a_1+I_{j+1}a_2+I_{j+1}I_{j+2}a_3+\ldots+ I_{j+1}I_{j+2}\ldots I_{j+n-2}\left(1+[I_{j+n-1}-1]\frac{m_2}{12}\right) a_n\right]$$

$$\text{where} \quad \sum_{i=1}^{n} a_i = C$$

For analytic convenience and because the a_i are virtually impossible to obtain, it is convenient to assume that the a_i are equal, and that $m_1 = m_2 = 6$.

The assumption of equal a_i is certainly not exact, but there are compensating effects which tend to make it more nearly so. For example, a large part of the initial contract amount is usually expended initially and toward the end of the contractual period. But, this is at least partially compensated for by the subsequent contract modifications which tend to distribute the expenditure of funds more uniformly over the contractual period.

Equation (1.1) then reduces to

$$(1.2)\quad C_I' = \left\{(I_j+1)\ \frac{1}{2}\right\} \frac{C}{n-1} \left[\frac{1}{2} + I_{j+1} + I_{j+1} \cdot I_{j+2} + \ldots + I_{j+1} \cdot I_{j+2} \ldots I_{j+n-2} \left([I_{j+n-1}+1]\ \frac{1}{2}\right)\ \frac{1}{2}\right]$$

C_I' is considered the best feasible estimate of the expected contract price at termination of contractual period if there are changes due only to inflation.

The numbers I_j are easily used to calculate future estimates of inflation including linear and higher order trends by a simple weighted average procedure.

It might also be pointed out that if H_j, H_{j+1}, ..., H_{j+k} are a set of coefficients, derived from the wholesale commodities W1, W_2, ..., W_{19} in Table 1, similar to the I_j but all normalized to the year (j-1)(instead of sequentially by preceeding year), then

$$H_\ell = \frac{W_\ell}{W_{j-1}}, \ell = 2, \ldots, 19,$$

and

$$I_j \cdot I_{j+1} \cdot I_{j+2} \cdots I_{j+k} = \frac{W_{j+k}}{W_{j-1}} = H_{j+k}.$$

This equation (1.2) reduces to:

$$(1.3) \quad C_I' \cong \frac{C}{n-1} \left[\frac{1}{2} H_j + H_{j+1} + H_{j+2} + \cdots + \frac{1}{2} H_{j+n-1}\right] .$$

Although the computational burden associated with 1.3 is far less than that associated with 1.2, the former requires a new set of coefficients, H_j, for each possible contract initial year and forfeits the advantage of the previously mentioned averaging process for extimating linear trends with the I_j.

The contract cost, C, in equation 1.2 can be factored out of the right hand side and the remainder of the term may be denoted simply by I. Then this equation may be written,

$$(1.4) \qquad C_I' = C \cdot I$$

I is the aggregate inflation index for the contractual period used in this analysis.

In periods of constant inflation,

$$I_j = I_{j+1} = \ldots = I_{j+n-1}$$ [and this is 1 during periods of no inflation].

C_I then reduces to,

$$C_I = \frac{C}{n-1}\left\{\frac{1}{2} + 1 + \ldots + 1 + \frac{1}{2}\right\} = C.$$

Therefore, if no inflation occurs throughout the entire contractual period, and the contractor uses the present inflation index as an estimate of the aggregate index I, then the expected increase (or decrease) due only to inflation (or deflation) is zero.

The analysis in Chapter III will consist in examining the contract data for correlation between overruns and the individual contract aggregate inflation indices. The amounts spent per year (the a_i), the quantities m_1 and m_2 and the amount of inflation planned for at the time of contract definitization are not known to us. It is therefore impossible to analyze in detail the relationship between the C_i corrected and uncorrected for inflation and the corrected amounts of money spent for each modification and for the final closeout which is directly attributable to inflation. For this reason, the coarser analysis has been undertaken in an attempt to detect inflation. If complete and accurate data were available, the exact amounts of the effect of inflation towards cost growth could be assessed. However, the coarse analysis can be expected only to detect the presence of inflation. Note that, if the analysis does not indicate the presence of an inflationary contribution to cost growth, then because of the crudeness of the model (due to the assumptions which were caused by a lack of data), it can not be said with confidence that the effect does not exist.

APPENDIX II

ELEMENTS OF MODEL BUILDING

Statistical analyses can be classified roughly into one of two categories. One category is that which occurs when the statistical analyst has a set of data which is generated by a known model. This model may, of necessity, contain many parameters; but all possible parameters are accounted for. The analysis is usually straightforward and inferences are drawn about the relative importance of the various parameters.

The analysis in this study is of the second variety. The data is generated by an unknown process; that is, the process may contain parameters which are not known, or not even suspected to belong to it. Frequently, the analyst pretends that the model is known and proceeds with the standard statistical tests, overlooking the fact that the model must first be constructed and then the analysis conducted. Ideally, the statistician can employ the methods of experimental design to partially overcome this problem, but it is rarely possible to design an experiment for gathering economic data. The following is presented to aid the uninitiated reader in interpreting the results of this study.

To introduce the problem, assume that the data points (x_1,y_1), ..., (x_n,y_n) have been generated by an unknown model which we

assume to be $y_i = \beta_o + \beta_1 x_i + \varepsilon_i$ where the x_i are known numbers and the y_i are the observed random variables subject to the individual error, ε_i. It is well known that the total sum of squares can be decomposed as follows:

$$\Sigma(y_i-\bar{y})^2 = \Sigma(y_i-\hat{y}_i)^2 + \Sigma(\hat{y}_i-\bar{y})^2$$

where $\bar{y} = \frac{1}{n}\Sigma y_i$ and $\hat{y}_i$ represents an estimate of $\beta_0 + \beta_1 x_i$ or $E(y_i)$. In words this can be described as,

$$\begin{pmatrix}\text{Sum of squares}\\ \text{about the mean}\end{pmatrix} = \begin{pmatrix}\text{Sum of squares}\\ \underline{\text{about}}\text{ regression}\end{pmatrix} + \begin{pmatrix}\text{Sum of squares}\\ \underline{\text{due to}}\text{ regression}\end{pmatrix}$$

The sum of squares about the mean is constant (does not depend on which model is used to obtain $\hat{y}_i$). Intuitively, it seems clear that reducing the sum of squares about regression by using a more accurate model would increase the sum of squares due to regression. This would increase the value of the F-ratio. However, the degrees of freedom associated with a "larger" model, then has a compensating effect on this ratio. The following remarks should make the preceding slightly less qualitative.

Suppose that $\underline{\beta}' = (\beta_0, \beta_1, \ldots, \beta_p)$ is a set of parameters which generates data according to the linear statistical model $\underline{y} = X\underline{\beta} + \underline{\varepsilon}$ where

$$X = \begin{bmatrix} 1 & X_{11} & X_{21} & \cdots & X_{p1} \\ 1 & X_{12} & X_{22} & \cdots & X_{p2} \\ \vdots & & & & \\ 1 & X_{1n} & X_{2n} & \cdots & X_{pn} \end{bmatrix} \quad \text{and}$$

$$\underline{\varepsilon}' = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n).$$

The elements of the matrix X are known and the ε_i are random error with $E(\varepsilon_i) = 0$, and Var $(\varepsilon_i) = \sigma^2$ It is well known (Graybill) that the least square estimates for the ε_i are obtained by the equation

$$X'X\hat{\underline{\beta}} = X'\underline{y}, \text{ or } \hat{\underline{\beta}} = (X'X)^{-1}X'\underline{y}$$

if $X'X$ is full rank. Also, $E(\hat{\underline{\beta}}) = \underline{\beta}$ and Cov $(\hat{\underline{\beta}}) = \sigma^2(X'X)^{-1}$. The regression due to $\underline{\beta}$ is $\hat{\underline{\beta}}'X'\underline{y}$ and the usual F statistic is:

$$F_o = \frac{\hat{\underline{\beta}}'X'\underline{y}}{(\underline{y}'\underline{y} - \hat{\underline{\beta}}'X'\underline{y})} \cdot \frac{(n-p-1)}{p+1} \sim F_{p+1,n-p-1}$$

Suppose now, that a sta' 'ical analysis has been conducted on data generated by the above model, but that only $r < p+1$ of the parameters have been included in the analysis. That is, the model used is,

$$\underline{y} = X_1\underline{\gamma}_1 + \epsilon \quad \text{where}$$

$$\underline{\gamma}_1' = [\beta_0, \beta_1, \ldots, \beta_r]$$
$$\underline{\gamma}_2' = [\beta_{r+1}, \ldots, \beta_p]$$
$$\underline{\beta}' = [\underline{\gamma}_1 | \underline{\gamma}_2]$$

$$X_1 = \begin{bmatrix} 1 & X_{11} & \cdots & X_{r1} \\ 1 & X_{12} & \cdots & X_{r2} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & X_{1n} & \cdots & X_{rn} \end{bmatrix}$$

$$X_2 = \begin{bmatrix} X_{r+1,1} & \cdots & X_{p,1} \\ \vdots & \vdots & \vdots \\ X_{r+1,n} & \cdots & X_{pn} \end{bmatrix} \quad \text{and}$$

$$X = [X_1 | X_2].$$

If the reduced model is assumed correct, then the apparent least square estimate of $\underline{\gamma}_1$ is:

$$\tilde{\underline{\gamma}}_1 = (X_1'X_1)^{-1}X_1'\underline{y}.$$

It is readily apparent that $\tilde{\underline{\gamma}}_1$ is not in general unbiased. Note that,

$$(4) \qquad X'X = \left[\frac{X_1'}{X_2'}\right] [X_1 | X_2] = \left[\begin{array}{c|c} X_1'X_1 & X_1'X_2 \\ \hline X_2'X_1 & X_2'X_2 \end{array}\right] ,$$

and the "normal" equation $X'X\hat{\underline{\beta}} = X'\underline{y}$ yields $X_1'X_1\tilde{\underline{\gamma}}_1 = X_1'\underline{y}$, so that $E(\tilde{\underline{\gamma}}_1) = \underline{\gamma}_1 + (X_1'X_1)^{-1}X_1'X_2\underline{\gamma}_2$. Only when $X_1'X_2 = 0$ is $\tilde{\underline{\gamma}}_1$ unbiased for $\underline{\gamma}_1$. This cannot be assumed in the above situation.

The F-ratio which would be used in this situation (incorrectly) is:

$$(5) \qquad F_0 = \frac{\tilde{\underline{\gamma}}_1'X_1'\underline{y}}{(\underline{y}'\underline{y} - \tilde{\underline{\gamma}}_1'X_1'\underline{y})} \cdot \frac{(n-r-1)}{r+1} .$$

The expected value for the denominator (mean square) is:

$$E\left[\underline{y}'[I-X_1(X_1'X_1)^{-1}X_1']\underline{y}/(n-r-1)\right] =$$

$$\sigma^2 + \underline{\gamma}_2'X_2'[I-X_1(X_1'X_1)^{-1}X_1'] X_2\underline{\gamma}_2/(n-r-1)$$

The numerator expected mean square is:

$$E(\tilde{\underline{\gamma}}_1'X_1'\underline{y})/r+1 = E(\underline{y}'X_1(X_1'X_1)^{-1}X_1'\underline{y})/r+1$$

$$= \sigma^2 + \frac{\underline{\gamma}_1'X_1'X_1\underline{\gamma}_1}{r+1} + [\underline{\gamma}_1'X_1'X_2\underline{\gamma}_2 + \underline{\gamma}_2'X_2'X_1\underline{\gamma}_1$$

$$+ \underline{\gamma}_2'X_2'X_1(X_1'X_1)^{-1}X_1'X_2\underline{\gamma}_2]/r+1$$

The apparent E.M.S.'s are σ^2 and $\sigma^2+\underline{\gamma}_1'X_1'X_1\underline{\gamma}_1/r+1$ respectively, which means that the true critical points could change drastically from the apparent ones. In order to gain more insight into this problem, we should compare the F-statistic used in the analysis with the F-statistic derived from the true model. The true F is:

$$(6) \qquad F = \frac{\hat{\underline{\beta}}'X'y - \hat{\underline{\gamma}}_2'X_2'\underline{y}}{\underline{y}'\underline{y} - \hat{\underline{\beta}}'X'y} \cdot \frac{(n-p-1)}{r+1}$$

Compare this with the apparent F, equation (5). To simplify the comparison, one is tempted to decompose into its components X_1 and X_2. We note that,

$$(X'X)^{-1} = \left[\begin{array}{c|c} X_1'X_1 & X_1'X_2 \\ \hline X_2'X_1 & X_2'X_2 \end{array}\right]^{-1},$$

and this may be shown to be:

$$\begin{bmatrix} [X_1'X_1-X_1'X_2(X_2'X_2)^{-1}X_2'X_1]^{-1} & -(X_1'X_1)^{-1}X_1'X_2[X_2'X_2-X_2'X_1(X_1'X_1)^{-1}X_1'X_2]^{-1} \\ -(X_2'X_2)^{-1}X_2'X_1[X_1'X_1-X_1'X_2(X_2'X_2)^{-1}X_2'X_1]^{-1} & [X_2'X_2-X_2'X_1(X_1'X_1)^{-1}X_1'X_2]^{-1} \end{bmatrix}$$

Now consider this from the multilinear model used in the present research. The model is:

$$y_i = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_p X_{pi} + \varepsilon_i.$$

The "corrected" model is more mathematically tractable and is:

$$y_i = \beta_0' + \beta_1(X_{1i}-\bar{X}_1) + \ldots + \beta_p(X_{pi}-\bar{X}_p) + \varepsilon_i.$$

It is assumed that the analysis is conducted without knowledge of all parameters so that the analyst actually uses the following model:

$$y_i = \beta_0' + \beta_1(X_{1i}-\bar{X}_1) + \ldots + \beta_r(X_{ri}-\bar{X}_r) + \varepsilon_i$$

where $0<r<p+1$. Then,

$\underline{\gamma}_1' = (\beta_0, \beta_1, \ldots, \beta_r)$ and

$\underline{\gamma}_2' = (\beta_{r+1}, \ldots, \beta_p)$. The normal equations are:

$X'X\underline{\hat{\beta}} = X'\underline{y}$ and

$X_1'X_1\underline{\tilde{\gamma}}_1 = X_1'\underline{y}$ respectively. Specifically these are:

$$\left[\begin{array}{cccc|ccc} N & 0 & \ldots & 0 & 0 & \ldots & 0 \\ 0 & S_{11} & \ldots & S_{1r} & S_{1,r+1} & \ldots & S_{1p} \\ \vdots & \vdots & \ldots & \vdots & \vdots & & \vdots \\ 0 & S_{1r} & \ldots & S_{rr} & S_{r,r+1} & \ldots & S_{rp} \\ \hline 0 & S_{1,r+1} & \ldots & S_{r,r+1} & S_{r+1,r+1} & \ldots & S_{r+1,p} \\ \vdots & \vdots & & \vdots & \vdots & \ldots & \vdots \\ 0 & S_{1p} & \ldots & S_{rp} & S_{r+1,p} & \ldots & S_{pp} \end{array}\right] \left[\begin{array}{c} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \vdots \\ \hat{\beta}_r \\ \hline \hat{\beta}_{r+1} \\ \vdots \\ \hat{\beta}_p \end{array}\right] = \left[\begin{array}{c} n\underline{y} \\ S_{1y} \\ \vdots \\ S_{ry} \\ \hline S_{r+1,y} \\ \vdots \\ S_{py} \end{array}\right]$$

where $S_{uv} = \Sigma_i (X_{ui}-\bar{X}_u)(X_{vi}-\bar{X}_v)$ and

$S_{uy} = \Sigma_i (X_{ui}-\bar{X}_u)(y_i-\bar{y})$.

The F-statistic for the hypothesis $\beta_1 = 0$ is:

$$F_o = \frac{\tilde{\beta}_1 S_{1y}(n-r-1)}{\Sigma(y_i-\bar{y})^2 - (\tilde{\beta}_1 S_{1y} + \ldots + \tilde{\beta}_r S_{ry})}$$

where the $\hat{\beta}_j$ are obtained through equation (4) with $X_1^{\prime}X_2 = X_2^{\prime}X_1 = 0$, and $\underline{\beta}^{\prime} = [\underline{\gamma}_1 | \underline{\gamma}_2]$. The F which should be used is:

$$F_o = \frac{\hat{\beta}_1 S_{1y} \quad (n-p-1)}{\Sigma(y_i-\bar{y})^2 - (\hat{\beta}_1 S_{1y} + \ldots + \hat{\beta}_r S_{ry}) - (\hat{\beta}_{r+1} S_{r+1,y} + \ldots + \hat{\beta}_p S_{py})}$$

Now, each of the terms $\hat{\beta}_j S_{jy} \geq 0$ since they are of the form $\tilde{\underline{\gamma}}^{\prime} X^{\prime} \underline{y} = \underline{\gamma}^{\prime} X^{\prime} X \,\tilde{\underline{\gamma}} \geq 0$. Thus, when testing a simple hypothesis with the incomplete model, the denominator of the F-statistic will not include the terms $-(\hat{\beta}_{r+1} S_{r+1,y} + \ldots + \hat{\beta}_p S_{py})$. This has the effect of decreasing the value of the test statistic itself, while the coefficient $n-r-1 > n-p-1$, and this tends to increase the value of the test statistic. The two effects, however, are not completely compensating if n is rather large, say 200. Even if $p = 20$ and $r = 1$, $(n-r-1)/(n-p-1) = 1.106$, a rather small increase. In this case, the neglected terms in the denominator could easily deflate the F-statistic below the significance level.

The above remarks are qualitative, but the following conclusions are worthy of note. The present study is of the "model building"

variety. There are unquestionably many causes of cost growth, therefore many parameters in the model. Initially, when testing a parameter for significance, a great deal of latitude should be allowed in comparing the F-ratios with the critical values at a given confidence level. As more and more significant effects are found, the F-ratios become more accurate as the previous discussion indicates. This implies that as important "contributors" to the model are discovered, they are included in the model for further analysis. At this point, that capability has not been included in this research.

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